Student Pages

Student Pages

Roller Coasters

Introduction

The roller coaster is a popular thrill ride at amusement parks. In order to make roller coasters fun as well as safe, a great deal of science, technology, engineering and math is required. Design and build a model roller coaster that sends a marble on a fast, fun and safe ride.

Concepts

- Kinetic vs. potential energy
- Friction
- Conservation of energy
- Engineering design

Background

Work is the act of using a force to move an object through a distance. In order to reach the highest point on a roller coaster, energy (work) must be used. The energy expended to raise a roller-coaster car to a higher position is "stored" in the car—the car now has *potential energy (PE)*. The potential energy of the roller-coaster car is related to its weight and height, and is equal to the mass (m) in kilograms of the car multiplied by the acceleration due to gravity (g, $9.8\ m/s^2$) multiplied by the relative height (h) in meters of the car above the ground (Equation 1). The unit of energy is the joule (J).

{14062_Background_Equation_1}
In this activity, a rolling marble will simulate a roller-coaster car. When the marble rolls downward along the track, its potential energy is converted into *kinetic energy*, or energy of motion. Kinetic energy (KE) is related to the mass (m) in kilograms (kg) and speed (v) in meters per second (m/s) of the object (Equation 2).
{14062_Background_Equation_2}
The marble's kinetic energy is converted back into potential energy as it rolls up the track. This is due to the *conservation of energy principle*. The conservation of energy principle states that energy cannot be created or destroyed—energy can only be converted from one form to another. Therefore, the initial potential energy the marble has at the release point will be completely converted into kinetic energy at the bottom of the roller coaster (neglecting frictional forces). Each time the marble rolls up the track, its potential energy increases and its kinetic energy decreases, but the total amount of energy remains the same (Equation 3). As the marble rolls down the track, its height decreases. Therefore its potential energy also decreases, and its kinetic energy increases as gravity causes the marble to accelerate.
{14062_Background_Equation_3}

Student Pages

Friction is a force that opposes motion. As the marble rolls along the track, friction occurs where the two surfaces come in contact with each other. The track exerts a friction force in the opposite direction as the motion of the marble. Friction causes some of the marble's kinetic energy to be converted to heat energy, which is not useful with respect to the marble's motion. If the track were long enough at the bottom, eventually all the kinetic energy of the marble would be converted to an unrecoverable form and the marble would stop. In general, rougher surfaces experience more friction than smooth surfaces and an object that rolls along a surface experiences less friction than it would if it were sliding across the same surface.

Experiment Overview

The purpose of this activity is to build a roller coaster out of the materials provided. The lab begins with an introductory activity to determine the starting height needed for a marble to travel through a loop without leaving the track. The results will be used to design a fast, yet safe roller coaster ride that meets all the design criteria and constraints given by the instructor.

Materials

Balance, 0.1-g capacity

Foam pipe insulation, 6'

Knife, plastic

Marbles, glass and steel, 1 each

Masking tape

Meter stick

Ring clamp (optional)

Support stand

Stopwatch or timer

Prelab Questions

1. Figure 1 represents a section of a roller coaster track. If a marble were rolling along the track, at which point would the marble
   a. have the most potential energy?
   b. be gaining kinetic energy and losing potential energy?
   c. have the most kinetic energy?
   d. have the greatest speed?

{14062_PreLab_Figure_1}

2. A 15-g marble is raised to the top of a roller coaster track 0.5 m high.
   a. Use Equation 1 from the *Background* section to calculate the potential energy of the marble. Remember: 1000 g = 1 kg.
   b. The marble is released and travels down the first slope of the track. Neglecting friction, how much kinetic energy does the marble have when it reaches the bottom of the slope?
   c. The marble traveled the entire length of the 3-meter track in 1.2 seconds. What was the marble's average speed?
3. When testing a roller coaster design, why is important to only make one change at a time before running the next trial?

Student Pages

Safety Precautions

Be sure to quickly capture the ball if it leaves the track. Wear safety glasses. Please follow all laboratory safety guidelines.

Procedure

Part A. Introductory Activity

1. Obtain the 6-foot piece of foam pipe insulation and note the scored line running along the length.
2. Using the scored line as a guide, cut the insulation in half lengthwise with a plastic knife (see Figure 2). {14062_Procedure_Figure_2}
3. Use masking tape to connect the two halves of the pipe together to make one 12-ft long U-shaped track. Make sure the seam where the two pieces meet is smooth so it does not interfere with the motion of the marble as it rolls along the track.
4. Attach one end of the track to a support stand so the end is 0.3 m above the floor. The vertical distance from the beginningof the track to the floor is the *rise*.
5. Form a loop by curling part of track. The top of the loop should be less than 0.3 m above the floor.
6. Tape the bottom of the loop to the floor.
7. Measure the horizontal distance in meters from the starting point to where the track touches the floor. This horizontal distance is the *run* (see Figure 3). The rise over the run (rise/run) is the slope of the first part of the track. {14062_Procedure_Figure_3}
8. Measure the horizontal distance in meters from the beginning of the run to the bottom of the loop.
9. In a notebook or separate sheet of paper, construct a data table to record the rise, run, distance to the loop and distance from the floor to the top of the loop.
10. Extend the remainder of the track along the floor in a straight line, taping where needed to keep it in place.
11. Place a barrier at the end of the track so the marble does not roll across the floor (e.g., a paper or plastic cup or two or three books to make a "fence").
12. Obtain one glass marble and one steel marble.
13. Measure and record the mass of each marble.
14. Choose one marble, glass or steel, and release it from the top of the track.
15. Note whether or not the marble makes it around the loop, and if it stays on the track the entire time.
16. Repeat steps 14–15 with the other marble.
17. Make adjustments as needed in the rise, run, or diameter of the loop in order to achieve success. Success is defined as the marble traveling down the slope and around the loop while remaining in contact with the track at all times for a minimum of five trials.
18. Once success has been achieved with either marble or both, draw and label a diagram of the track, including measurements of the rise, run, distance to the loop and height of the loop for Part A on the Roller Coasters Worksheet (use Figure 3 as a guide).

Part B. Design Challenge

The challenge is to design and construct a roller coaster with two special features, either two loops or a loop and a hill. The roller coaster must meet the following criteria and constraints.

Student Pages

- The ride must be safe—the marble must remain in contact with the track at all times during each of three trials.
- The marble must stop at or near the end of the track without falling off. It cannot "crash" into a barrier, but must slow down and come to a stop as close to the end as possible.
- Masking tape may be used to keep the structure of the track in place.
- Other objects may be used to raise the level of the track at any point.
- Masking tape or sandpaper strips, available from the instructor, may be used to provide more friction on the track.
- The time of the ride from the release of the marble to when it stops must be measured.
- The distance from the end of the track where the marble stops must be measured.

Form a working group with other students and discuss following questions to aid in the experimental design.

1. Which marble will you use for your roller coaster? Be prepared to give a reason for your choice.
2. Did any part of Part A contribute to inconsistencies in the way the marble traveled along the track? If so, how can more consistency be achieved?
3. How does the speed of the marble change as it goes around a loop or up and down a hill?
4. How might the answer to the above question help determine where the special features should be located along the track?
5. What are some possible ways to slow the marble down before it reaches the end?
6. Why is it important to draw and label your design with accurate measurements and to record observations and any adjustments made during testing?

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